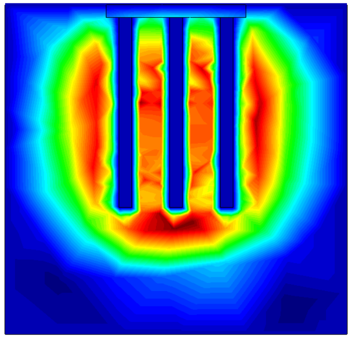

# Geotechnical Design of Heat Exchanger Piles

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Claire SILVANI

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# Outline

1. The energy pile technology today
2. Some features of the thermo-mechanical behaviour of the system energy pile / surrounding ground
3. Geotechnical design tool for heat exchanger piles, validation and optimal design
4. Conclusion

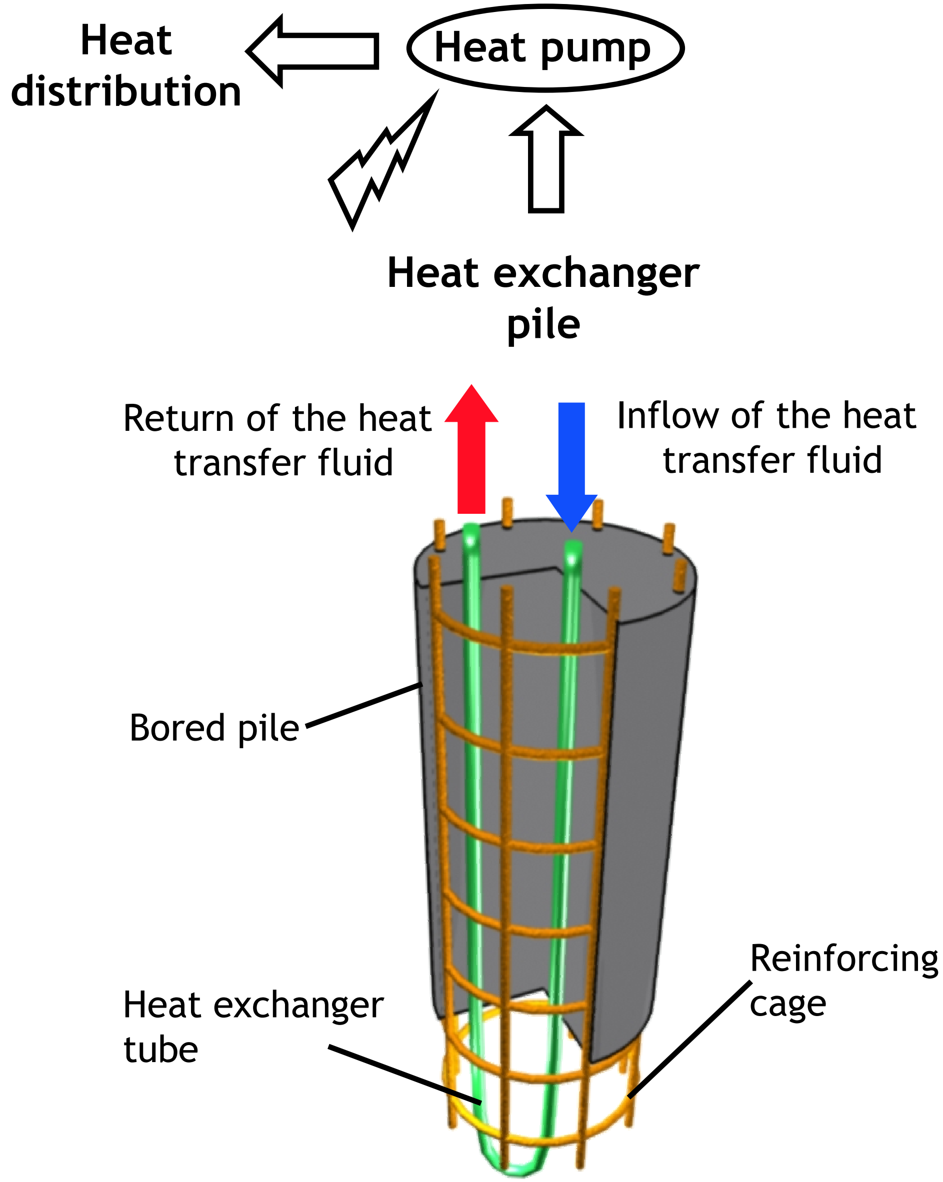
# Principle of Heat Exchanger Piles

- The heat exchange is made via the foundations of the building

-The energy transfer is made via a fluid circulating in pipes cast in the piles

- Optimal efficiency: heat extracted in winter re-injected in summer


(Source: Lippuner & Partner AG, Grabs)



# Advantages of the system

- **Cost efficiency and reliability:**

Local source of energy: almost no energy transportation, secure and rational supplying.

Minor additional energy supply (electricity for the heat pump).

Minor modifications in the foundation, no additional structure is required (compared to classical geothermal structures):

- **Environmentally friendly technology:**

Most of the energy is simply the heat naturally present in the ground

Example: Zürich airport terminal E, 75 % of the used energy for heating and cooling comes directly from the energy piles.

# Main realizations

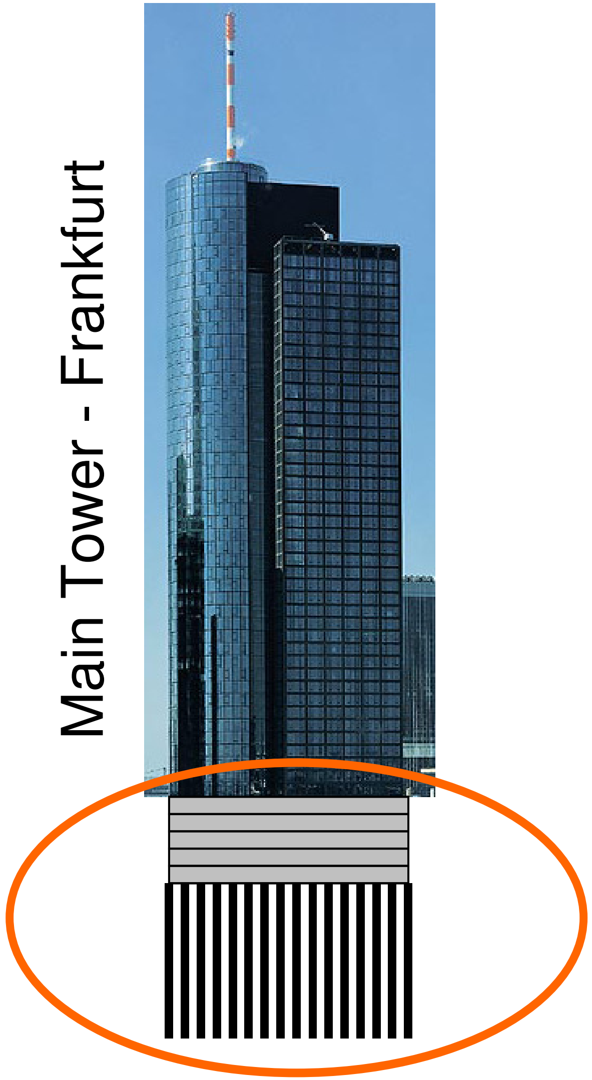
## Constructions using thermal piles (about 40 in Switzerland):

- Finkernweg (75 thermal piles)
- Lidwil (120)
- Pago (570)
- Photocolor at Kreuzlinger (93)
- Etc.


(Source: Lippuner & Partner AG, Grabs)

# Main realizations

- Main Tower – Frankfurt am Main
- 112 energy piles (1.5 m in diameter and 30 m in length) + diaphragm wall composed by 110 heat piles
- Soil affected volume: 150’000 m3
- Power withdrawn from the soil: 500 kW

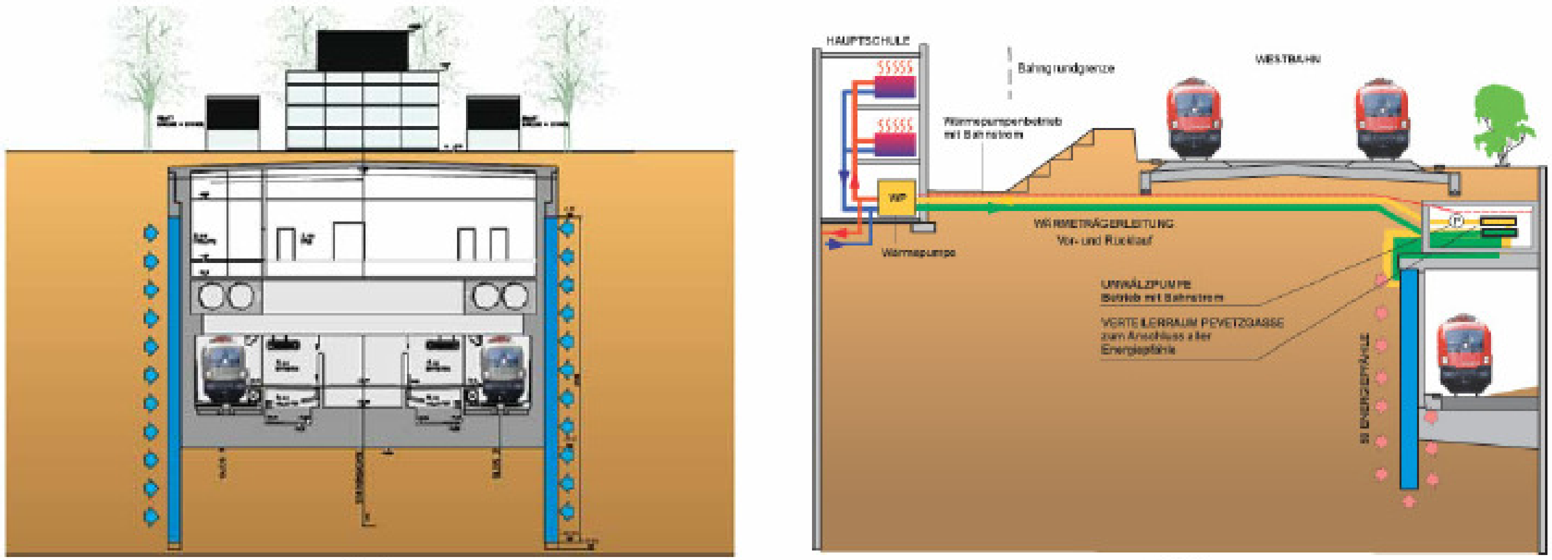


# Main realizations

Figure 3- Zürich Dock Midfield terminal (source: geothermie.ch)

- Zurich Airport – Dock Midfield terminal
- 300 energy piles (90 and 150 cm in diameter and 30 m in length)
- Soil affected volume: 200’000 $m^3$
- Power withdrawn from the soil: 2700 MWh/yr

# Main realizations




(a) (b)

Figure 6- Underground railway station (a) with diaphragm walls (Vienna, Austria), and Lainzer tunnel (Vienna, Austria) with piled retaining wall with piles (Source: Enercret®, Project sheet)

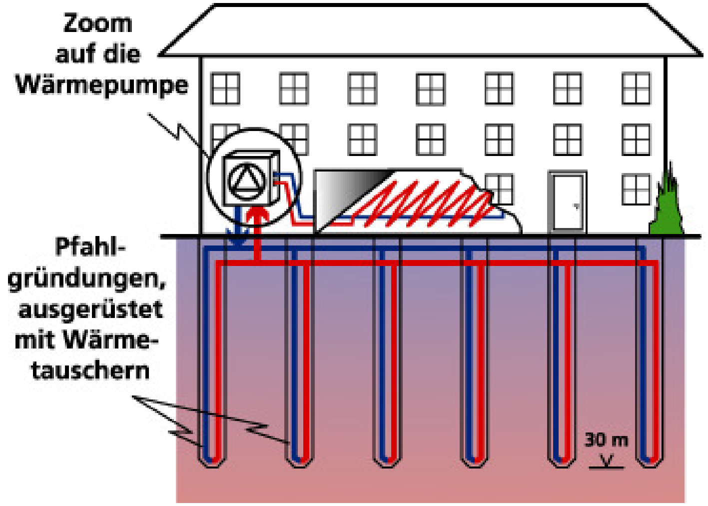
- Lainzer tunnel, Vienna
- Piled retaining wall with piles
- Power withdrawn from the soil: 144 MWh/yr

# Challenge in geotechnical engineering

- The design today: adapted from geothermal probe design

From the building energy demand and soil/concrete *thermal* (and hydraulics) properties, design of the heat pump + piles.

Lack of understanding…




Source: www.geothermie.ch

- No adapted *geotechnical* design of the energy piles!

- Safety factors are twice usual (without heat exchange) systems.

- Typical behaviour: increase the number of piles, width and length, which increases the cost.

NEED FOR UNDERSTANDING of heat exchanger pile / soil system mechanical behaviour.

NEED FOR DESIGN TOOL based on a sound knowledge of the processes.

1. The energy pile technology today

2. **Some features of the thermo-mechanical behaviour of the system energy pile / surrounding ground**

3. Geotechnical design tool for heat exchanger piles, validation and optimal design

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# Modelling: influence of temperature on mechanical behaviour

**TEMPERATURE induces COMPLEX NON-LINEAR PROCESSES relating to the SOIL MECHANICAL BEHAVIOUR.**

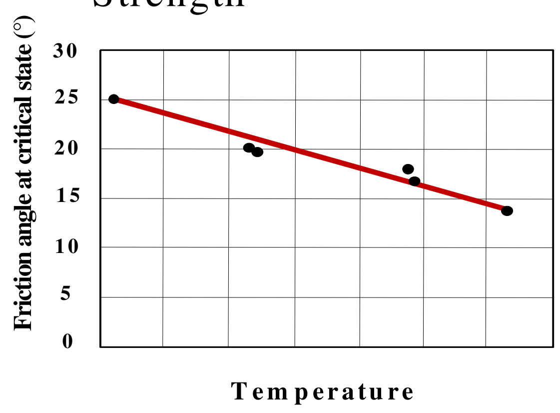
Main aspects:

Change in friction angle (soil strength)

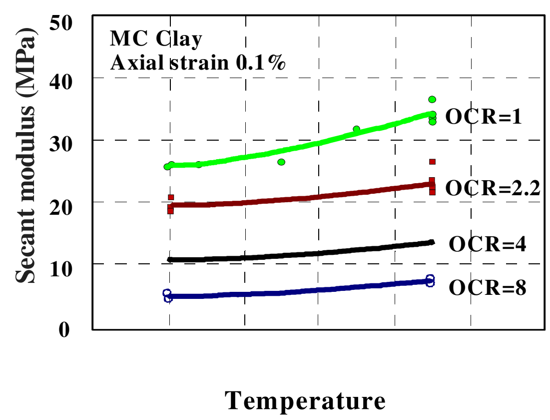
Thermo-elasticity

New processes: irreversible contraction upon heating → THERMOPLASTICITY

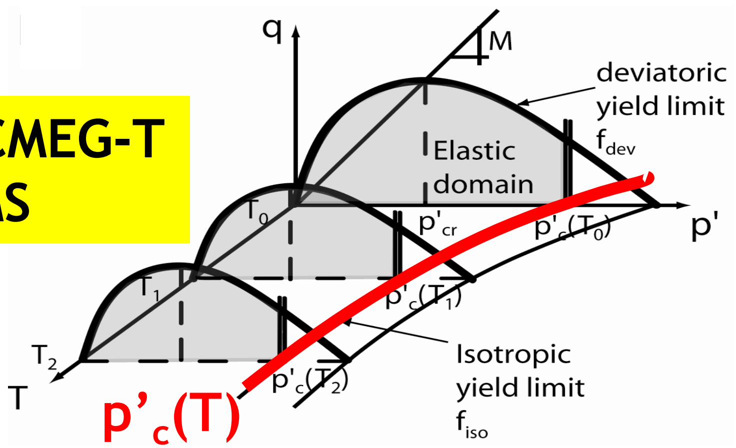
Strength




Stiffness



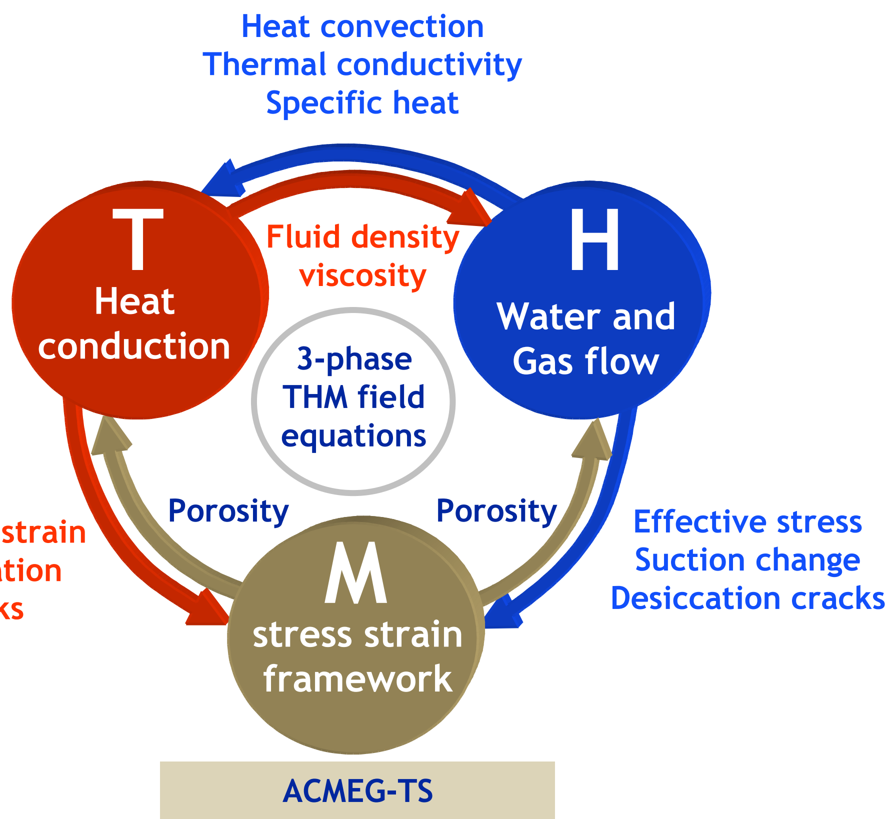

**Constitutive model ACMEG-T developed at EPFL-LMS**

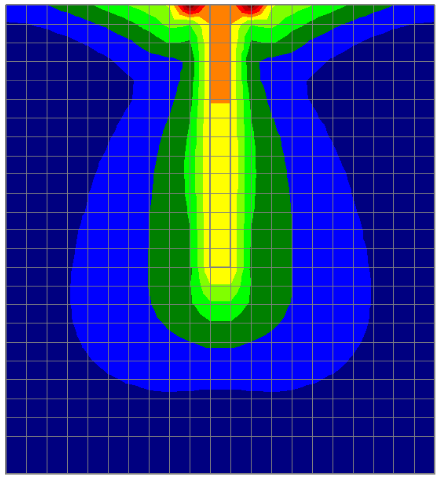


# Modelling: application to soil-pile system

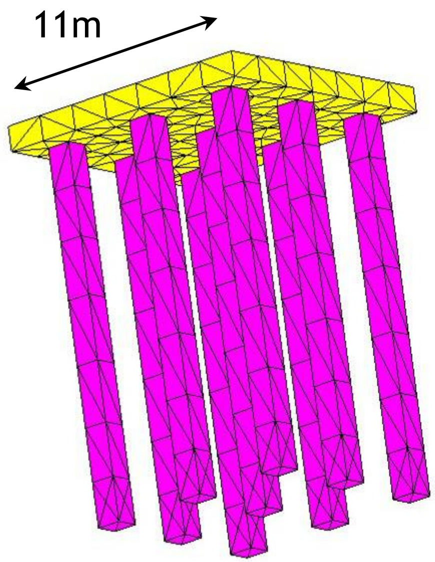
- Numerical tool: Finite Element code

Coupled formulation: displacements, pore water pressure and temperature are the field variables. Requires boundary and initial conditions



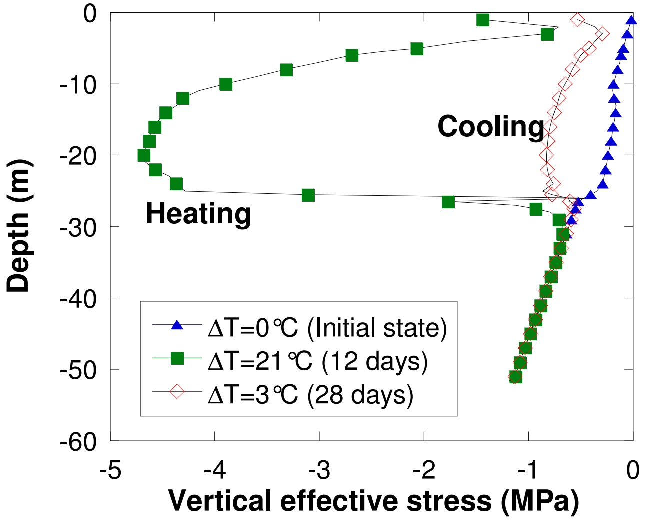



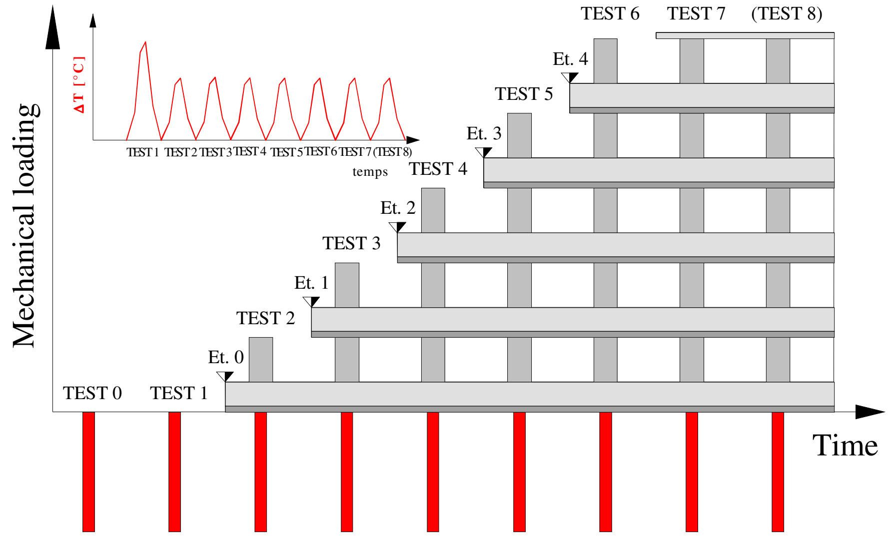
Single pile

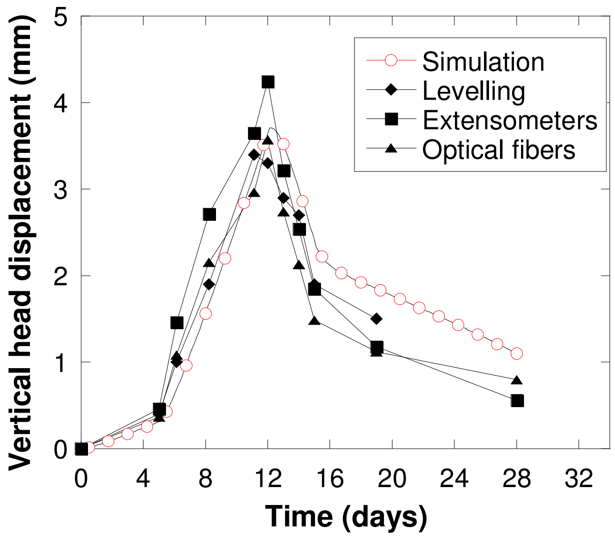


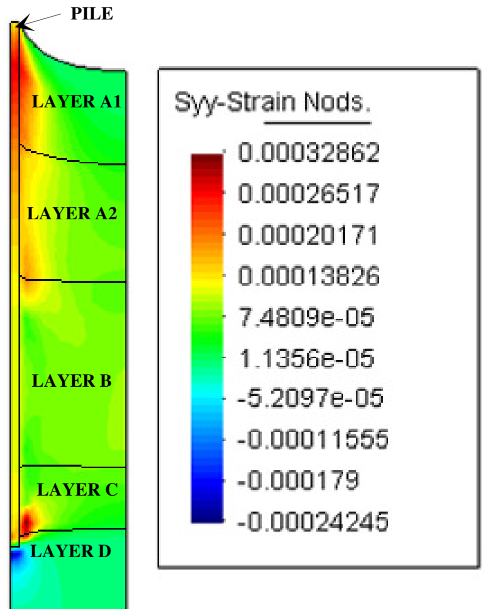

Group of piles

# Modelling: soil - single pile system



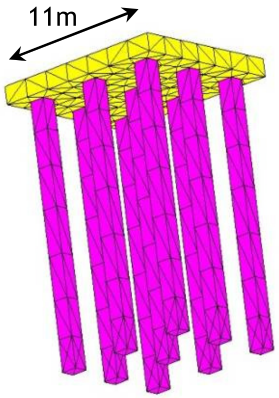



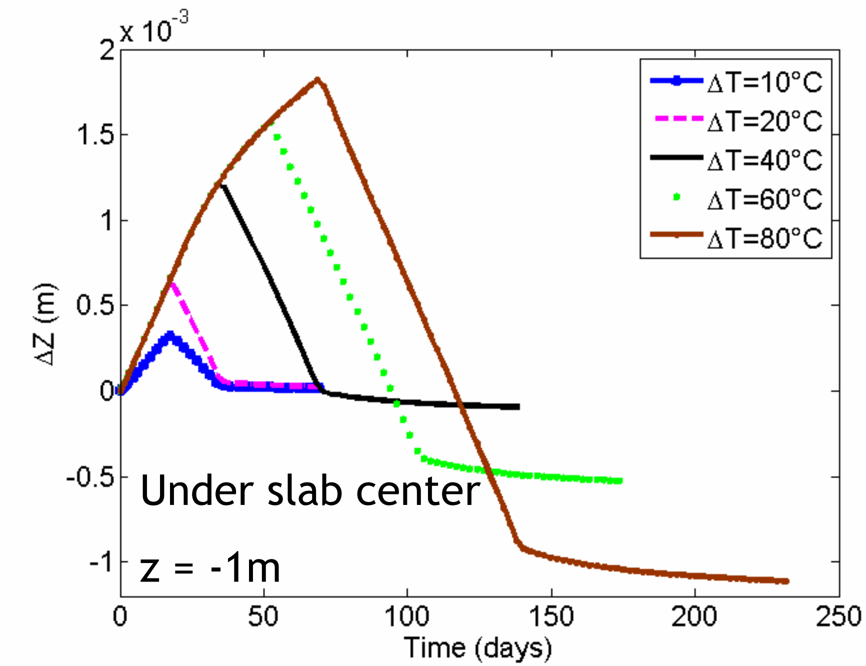



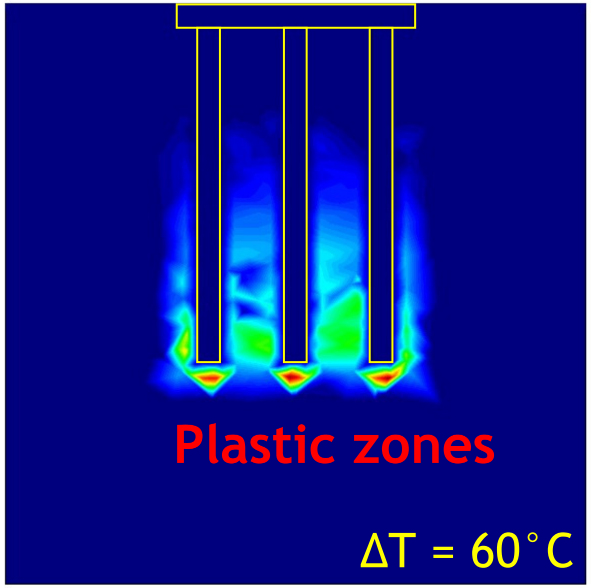

Heat induced deformations (x1425.15)

# Modelling: soil - group of piles system

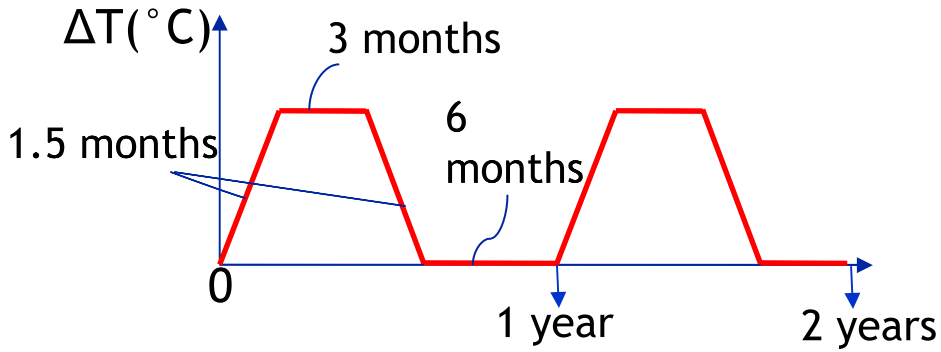
- Influence of the range of temperatures variations




- Influence of cycles on behaviour of energetic geostructure ΔT=60 (°C)



# Conclusions

**Outcome of the THM simulations:**

- Increase of the overall load within the pile upon heating

- Decrease of the overall load within the pile upon cooling

- Additional pile displacements

- Modification of the shaft friction mobilization along due to pile uplift or settlement

- Complex non-linear processes relating to the SOIL mechanical behaviour (thermo-hydro-mechanical couplings): cyclic thermo-plasticity. Assessment of the temperature range to avoid irreversible settlements

- "Exceptional situations", e.g. heat pile failure, "non-conventional" loadings. Assessment of differential settlements and the excess of stresses that may lead to injuries to the structure.

## New design tool: ThermoPile

1. The energy pile technology today

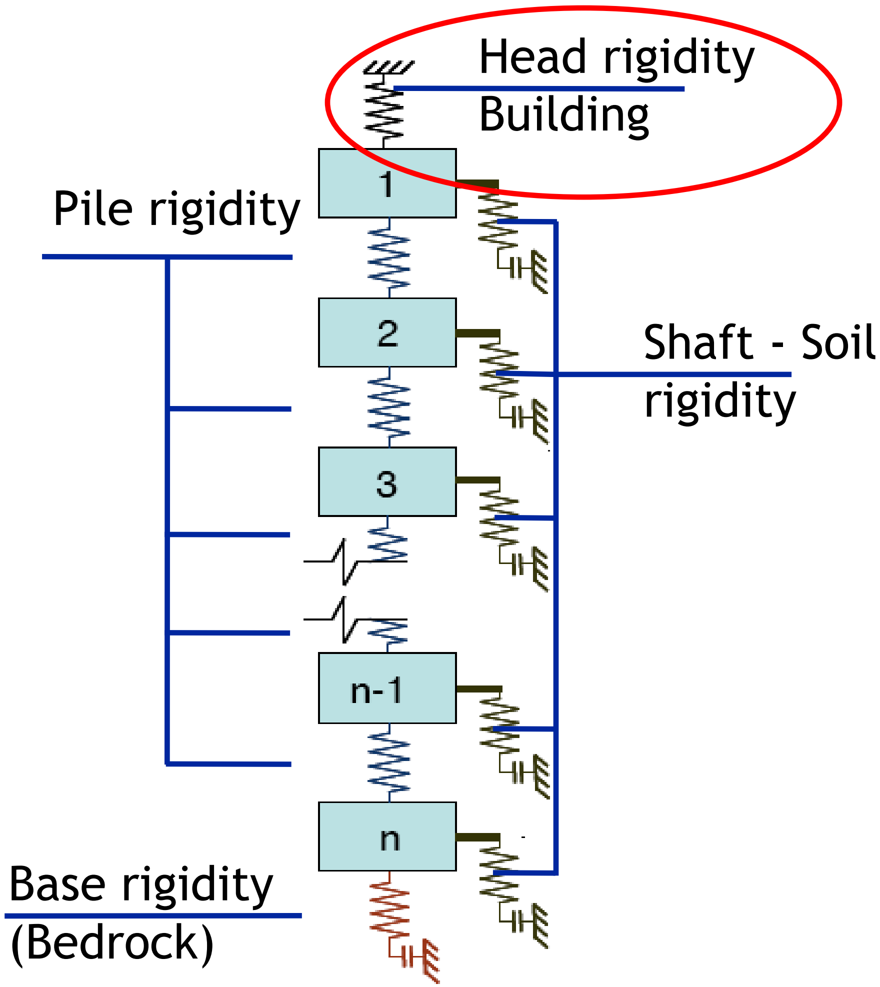
2. Some features of the thermo-mechanical behaviour of the system energy pile / surrounding ground

3. **Geotechnical design tool for heat exchanger piles, validation and optimal design**

4. Conclusion

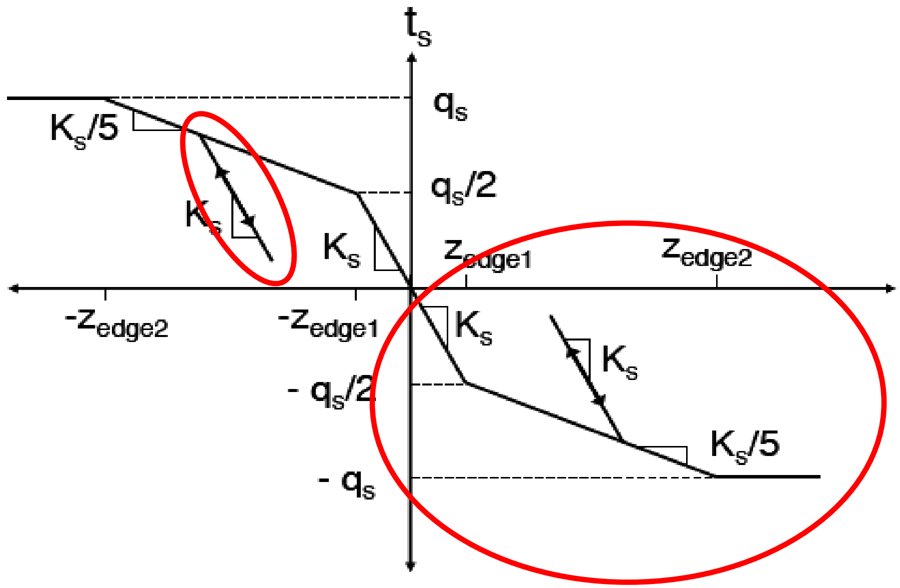
# ThermoPile: main assumptions

## Finite difference scheme

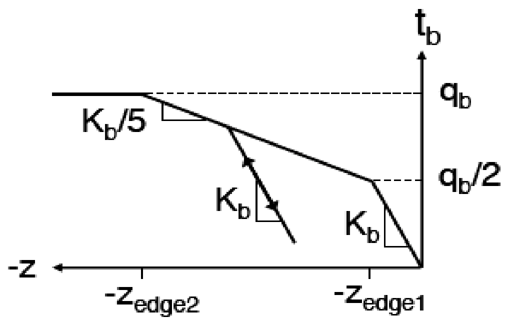



## Pile shaft – soil rigidity

(after Frank and Zhao 1982)



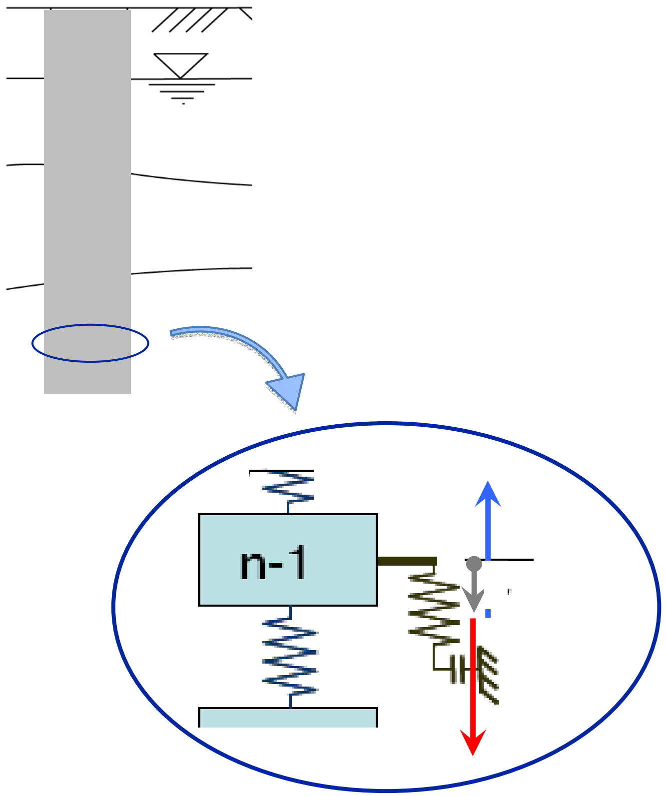

## Pile base – soil rigidity

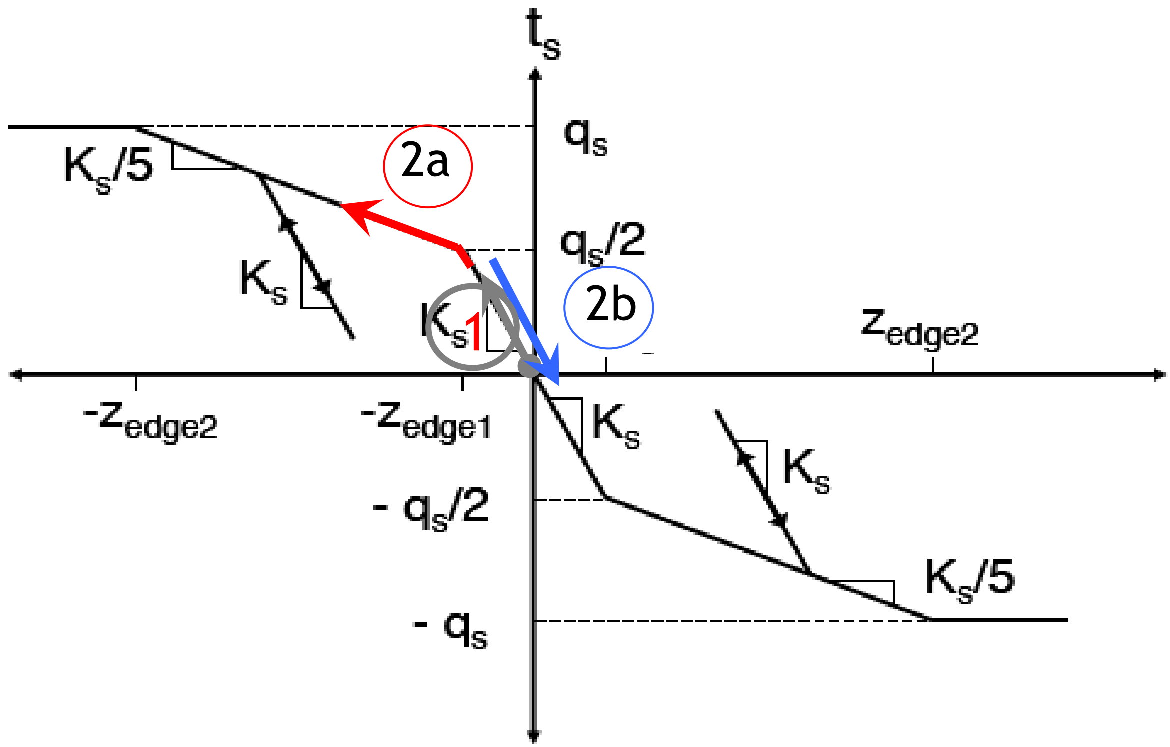


# ThermoPile - mechanical and thermal loading

Step 1: Displacement / stress calculation under mechanical loading
*(corresponds to a conventional settlement calculation after Coyle and Reese)*

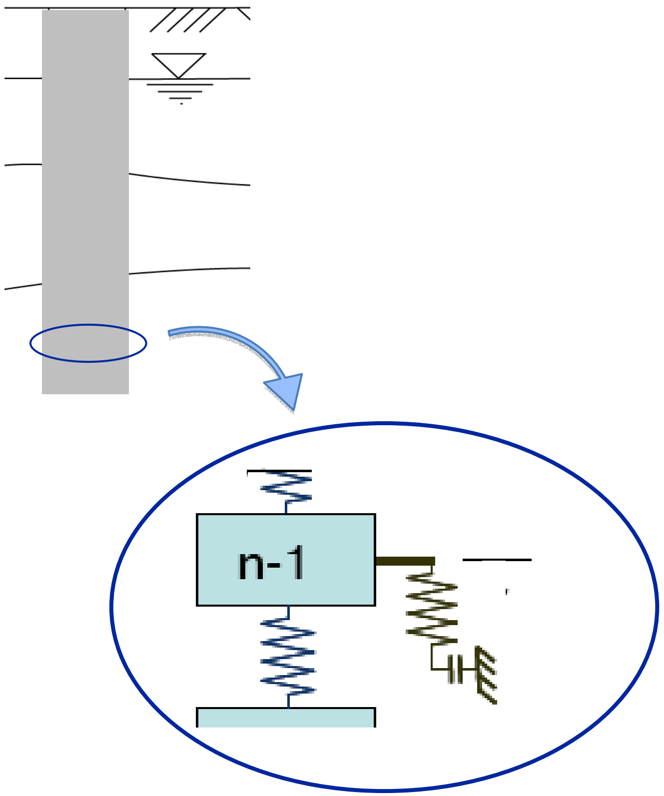
Step 2: Displacement / stress under thermal loading (heating / cooling)

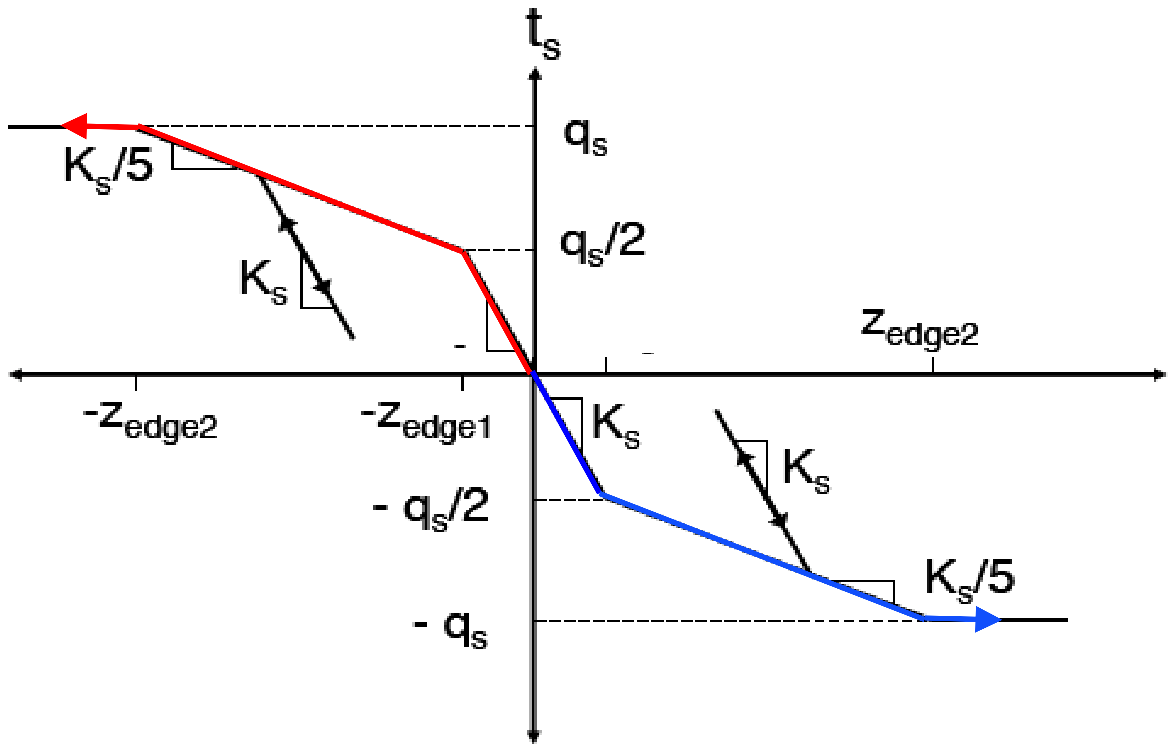


# ThermoPile - ultimate bearing capacity

The ultimate bearing capacity is reached when the plateau value $q_s$ of all the modelled springs is reached.



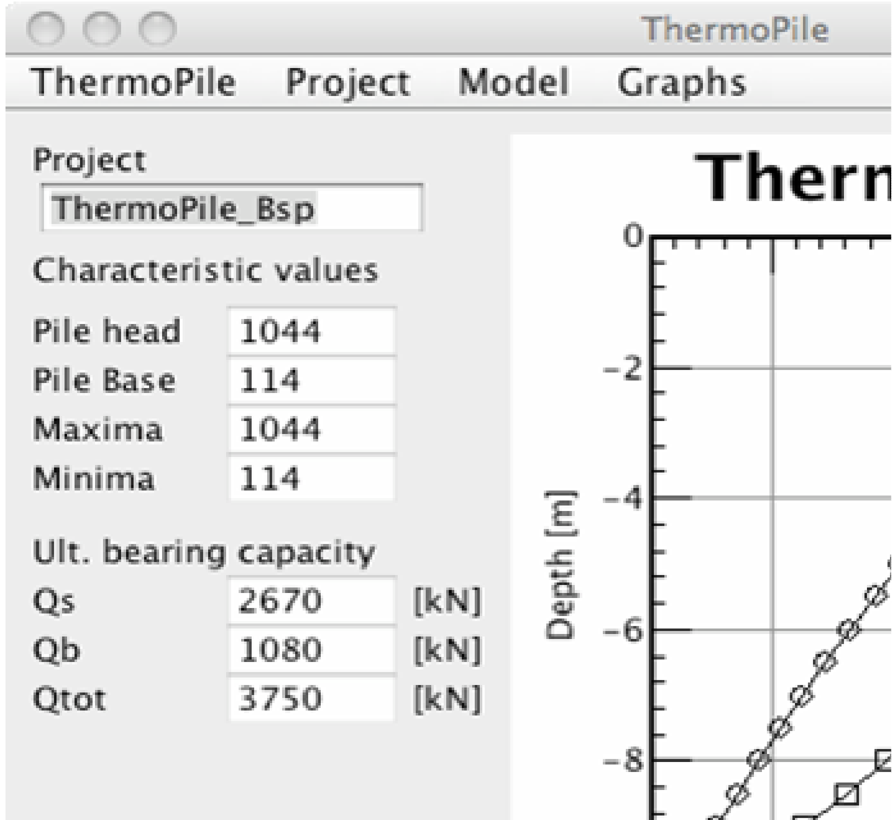
# ThermoPile - other features

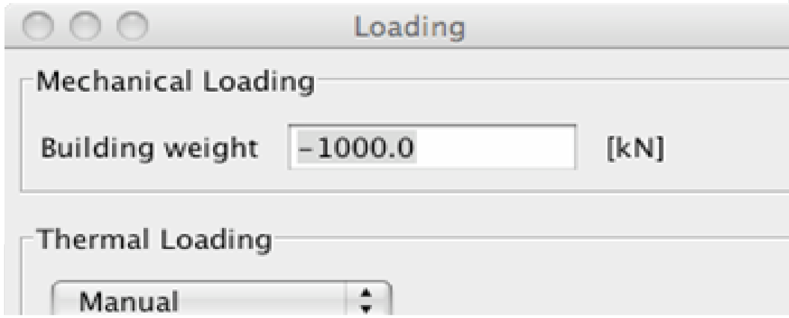
- Standard calculation of bearing capacity and settlement

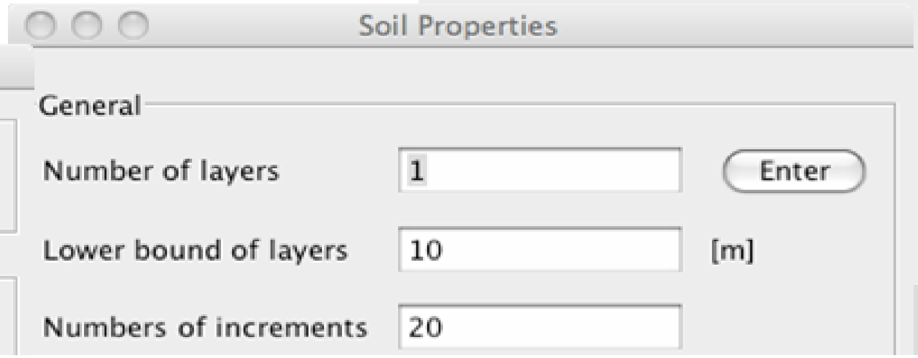
- Determination of the additional stresses and strains in pile due to thermal loading

- Modelling of multi layer soils

Includes:
- 2 theories to asses the bearing capacity (DTU, Lang and Huder)
- 2 Load transfer curves
- Possibility of manual entry

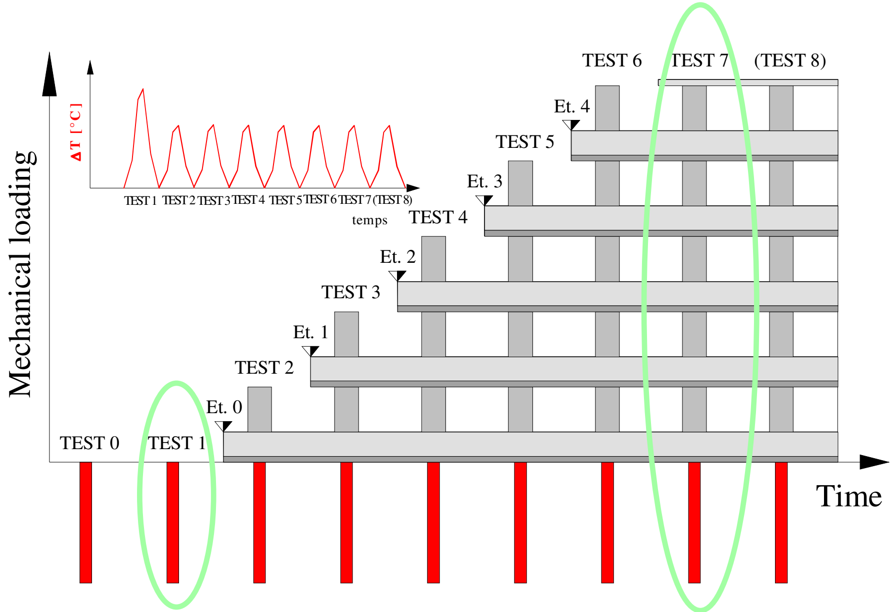


# ThermoPile - validation

## EPFL CASE STUDY




Test 1:
Mechanical load P = 0 kN
(no Building)
DT = 21.8
Test 7:
Mechanical load P = 1000 kN
Stiffness Pile – Structure = 2 GPa/m
DT = 14.3°C

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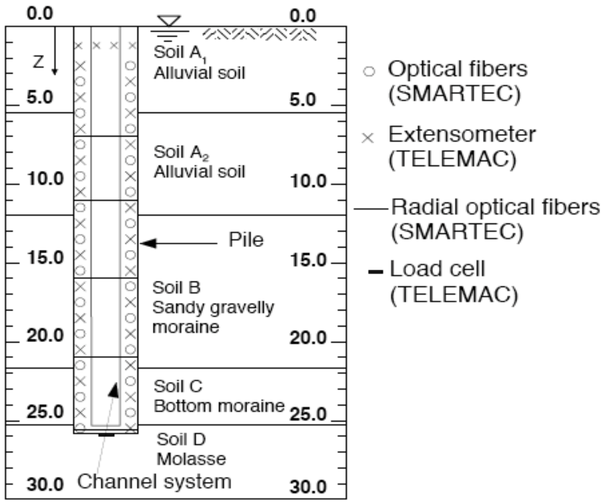
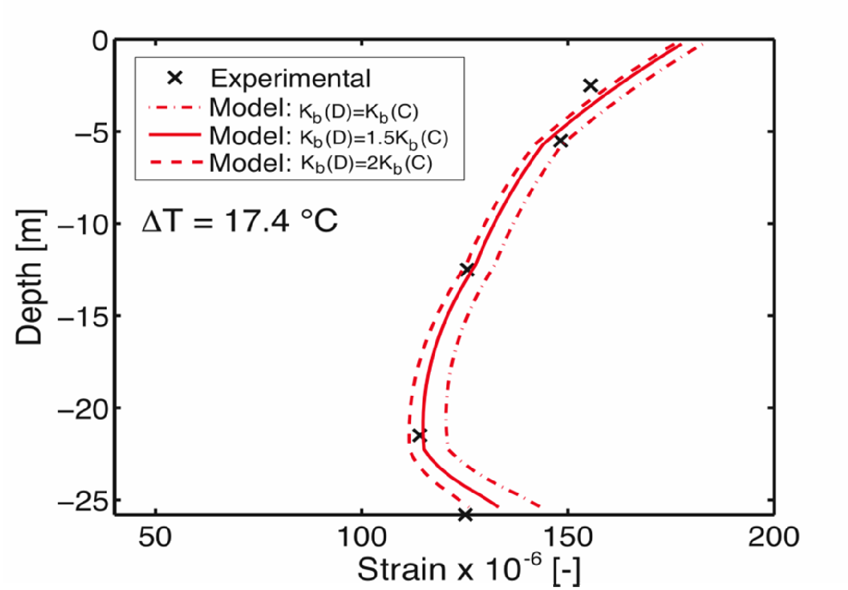
# ThermoPile - validation

## EPFL CASE STUDY

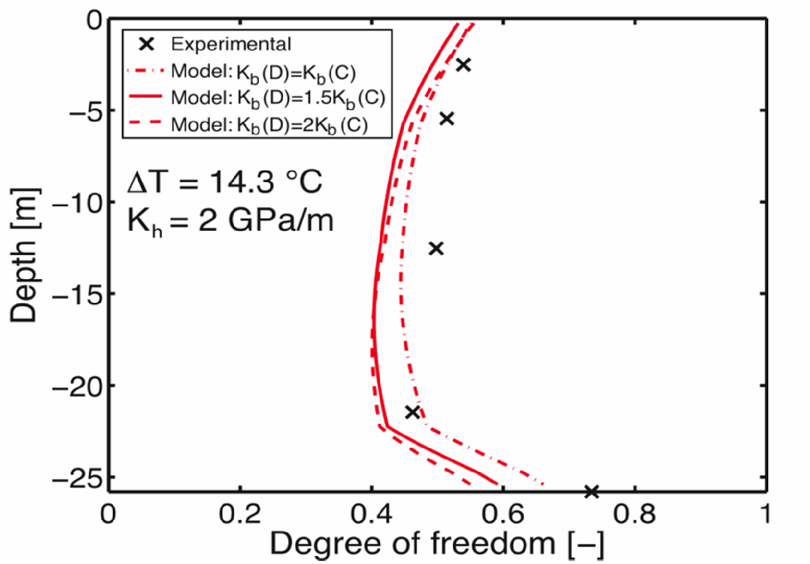



Test 1:




Test 1:
Mechanical load P = 0 kN
(no Building)
ΔT = 21.8

Test 7:

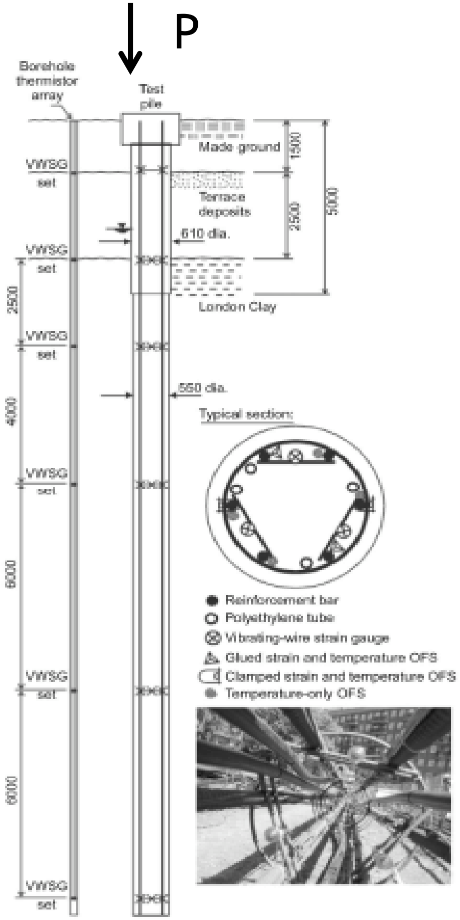



Test 7:
Mechanical load P = 1000 kN
Stiffness Pile – Structure = 2 GPa/m
ΔT = 14.3°C

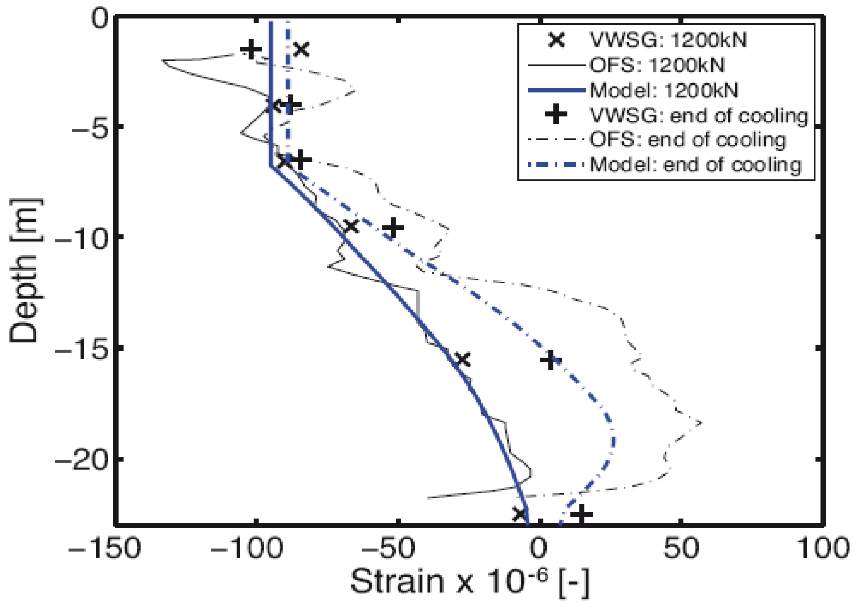
# ThermoPile - validation

## LAMBETH COLLEGE CASE STUDY

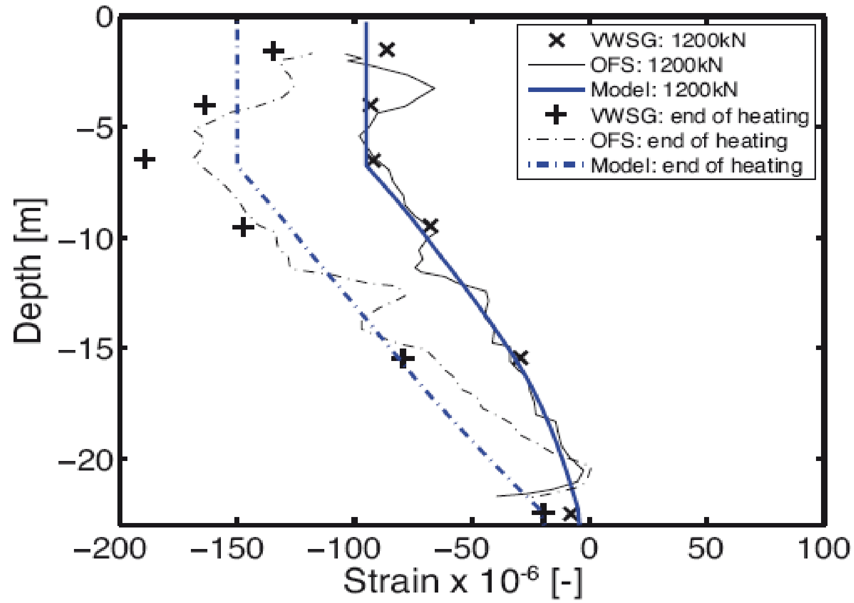
Mechanical load P = 1200 kN




Cooling:
$\Delta T$ = -19°C




Heating:
$\Delta T$ = +9°C

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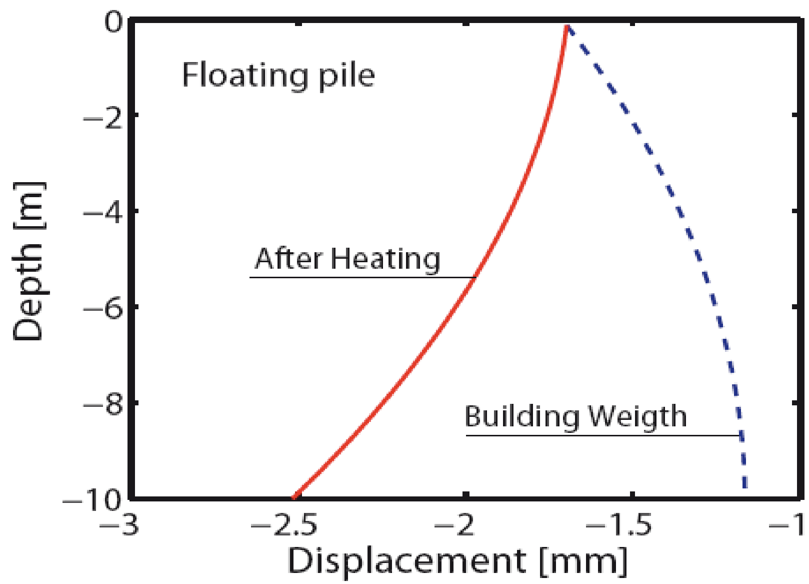
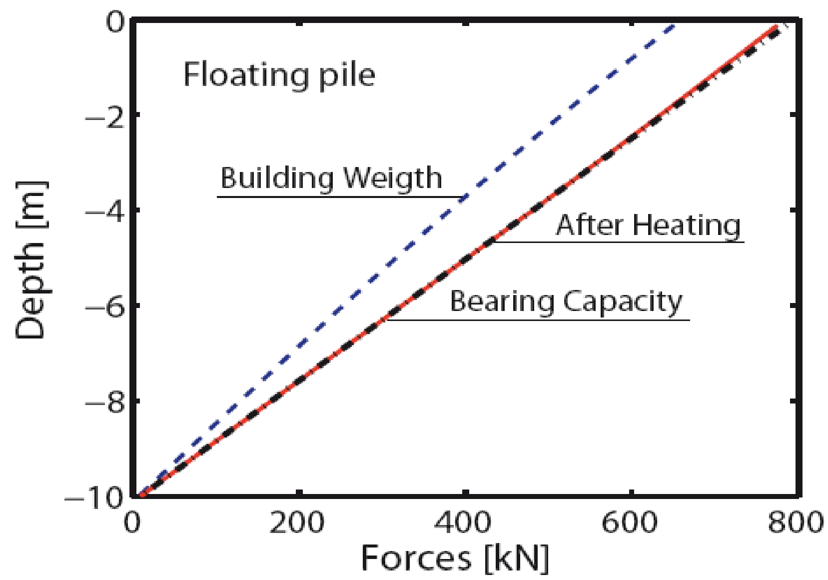
Cementation SKANSKA

# ThermoPile - Design of a floating pile

## Heating

| | |
|---|---|
| Pile Length: | L = 10 m |
| Pile Diameter: | D = 0.5 m |
| Thermal loading: | **$\Delta T$ = +15 °C** |
| Ultimate shear stress capacity: | $q_s$ = 50 kPa |
| Ultimate bearing capacity at pile base: | $q_b$ = 0 kPa |
| Menard Modulus: | $E_M$ = 20 MPa |



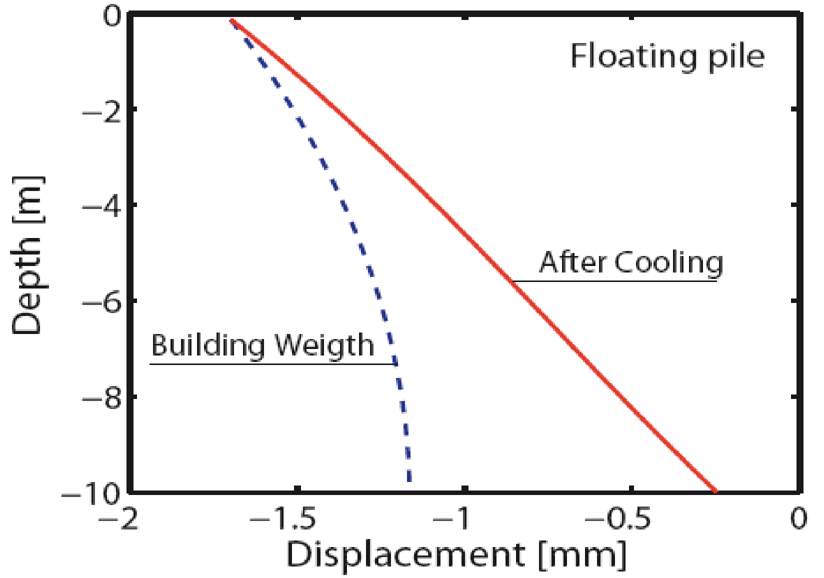

**Main aspect to consider during the design:**

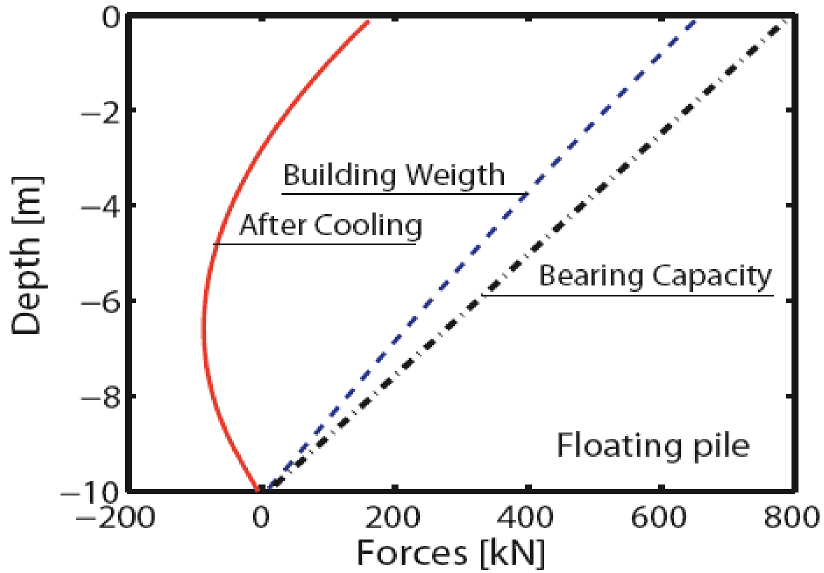
Bearing capacity can be reached

# ThermoPile - Design of a floating pile

## Cooling

| | |
|---|---|
| Pile Length: | L = 10 m |
| Pile Diameter: | D = 0.5 m |
| Thermal loading: | **ΔT = -15°C** |
| Ultimate shear stress capacity: | $q_s$ = 50 kPa |
| Ultimate bearing capacity at pile base: | $q_b$ = 0 kPa |
| Menard Modulus: | $E_M$ = 20 MPa |




**Main aspect to consider during the design:**

Tensile forces

# Optimization of hat exchanger pile systems

With the developed tool, we know the evolution of the efforts and the mobilized friction in the pile for different temperatures.

Proposed methodology:

- The pile system can be first designed with respect to the energy demand only.

- This leads to a given number of piles with a certain length and some temperature profiles along the piles.

- The safety of the pile can then be verified: in case of failure, the geotechnical design of the system can be re-assessed using the new tool.

1. The energy pile technology today

2. Some features of the thermo-mechanical behaviour of the system energy pile / surrounding ground

3. Geotechnical design tool for heat exchanger piles, validation and optimal design

4. **Conclusion**

# ACHIEVEMENTS OF THE PROJECT

Higher and larger buildings are now equipped with heat exchanger piles. But there is currently no method for the geotechnical design taking into account the effects of temperature cycles applied to the pile/soil system.

The numerical tool *ThermoPile* is an alternative to cumbersome FE modelling and expensive in situ tests. It can be considered as a handy and practice-oriented tool, offering a standard calculation method, which provides with useful results in a short time.

*ThermoPile* paves the way for an optimized geotechnical design of heat exchanger piles, therefore to reduce the safety factors applied (larger than the values usually employed for classical piles).

*The software will be available from May 2010*
*Information on* http://lms.epfl.ch/

# Thank you for your attention.